PEDESTRIAN HEADFORM IMPACT TESTS FOR VARIOUS VEHICLE LOCATIONS

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Paper Number 278

ABSTRACT

Current accident analysis shows that the head of the pedestrian impacts most frequently into or around the windscreen since cars in recent have a short hood. Therefore, the injury risks to the head in contact with various locations of the car including the windscreen and its frame were examined on the basis of headform impact tests. The HIC is high from contact with the cowl, lower windscreen frame or A pillar, and it is low with increasing distance from these structural elements. In the windscreen center, the HIC is less than 500.

The headform impact test results were compared between earlier and current car models. The HICs in the bonnet top area are similar in either type car except for the car built especially for pedestrian safety. However, on the A pillar, the HICs are much greater for current cars.

From child headform impact tests for the WAD of 1000 mm, the HIC of SUV is higher than cars, and the SUV with steel bull bar leads to high injury risk.

INTRODUCTION

Since the body of the pedestrian impacts various locations of the car, sub-system tests using impactors are effective to evaluate the injury risk to each body region. The European Enhanced Vehicle-safety Committee (EEVC) proposed three sub-system tests: headform impactor to bonnet top, legform to bumper, and upper legform to bonnet leading edge [1]. The International Harmonized Research Activities (IHRA) Pedestrian Working Group and International Standard Organization (ISO/TC22/SC10/WG2) also presented similar sub-system tests.

Head injuries pose a serious threat to life, and complete recovery is often not possible. In pedestrian-vehicle impact, the head is also the most frequent injured body region resulting in death [2]. Thus, it is most important to evaluate injury risks to the head.

The EEVC test method prescribes that the adult head impact test shall be made on the bonnet top within the boundaries defined as a wrap around distance (WAD) of 1500 mm and 2100 mm at a velocity of 40 km/h [1]. In this test method, the windscreen and A pillars are excluded from the test area. The EEVC presented these test methods in its first report of EEVC WG10 [3]. However, when these pedestrian test methods were firstly discussed, most cars had an upright frontal area and a long hood. Since modern cars have become smaller and have a short and steep bonnet, the head impact locations have changed from the hood to the cowl or windscreen in actual accidents [2][4]. Thus, it was suggested that the injury risks to the head by contact on and around the windscreen should be investigated [5]. Therefore, in this study, injury risks to the head of the pedestrian upon impact on and around the windscreen were examined based on headform impact tests.

Current cars must satisfy the requirements of frontal and side impact tests, so the current car construction is stiffer than that of earlier car models. Some cars were especially designed to reduce the injury risk to the pedestrian head [6]. The headform impact tests were performed on the hood top and windscreen frame for earlier and current car models.

Elderly people as well as children aged 5 or 6 years old sustain numerous injuries. To investigate the head injury risk to children, child headform impact tests were also carried out on the hood top of the sedans where the head of child is inclined to make contact.

Accident data show that the injury risk to children when struck by the SUV (Sports Utility Vehicle) is higher than for cars [4]. Some steel bull of aftermarket can be installed to SUV, which may cause high injury risk to a child's head. Therefore, the head injury risk to children was examined for the SUV with or without a bull bar from child headform impact tests. Since present genuine bull bars are made from plastic, a test was also performed on this plastic bull bar to examine the reduction of the injury risk to the head.

METHODOLOGY

Adult Headform Impact Tests Around Windscreen

Current accident data show that the pedestrian head frequently makes contact with and around the windscreen. Therefore, headform impact tests were carried out to evaluate injury risk to the head on impact with and around the windscreen. The adult headform impactor prescribed for the proposed EEVC pedestrian test procedures [3] was used. The outer layer of the impactor is composed of a skin and sphere, with a mass of 4.8 kg. The acceleration is measured at the impactor's center of gravity. The impact velocity is 40 km/h, and the impact angle is 65 degrees from the horizontal plane. Various locations such as the hood top (WAD of 1500 or more), cowl, fender, windscreen and its frame were impacted. In the case of the windscreen, the impact positions varied in proportion to the distance from the windscreen frame and A pillar. The Head Injury Criteria (HIC) were calculated for impacts on each area of the car.

Velocity has a large effect on the injury risk to the pedestrian. Mathematical simulation showed that the pedestrian's head hit the vehicle at differing velocities depending on the vehicle shape [4]. Therefore, we performed impact tests against the hood and windscreen at impact velocities of 30, 40 and 50 km/h, and compared the HIC values.

The same small car model: A 1990 model Toyota Corolla was used in the tests. The windscreen of this car is of laminated safety glass which consists of three layers: an outer glass layer, a polywinyl butyral (PVB) film and an inner glass layer. The thickness of the outer and inner glass is 2.3 mm, and that of the PVB film is 0.76 mm, which are the specifications commonly used for windscreens.

To compare the performance of the current and previous car models, headform impact tests were also performed for the current 1999 car models, such as Honda Life, Nissan Sunny and Toyota Ipsum (Picnic). The Life is a minicar with countermeasures taken for head impacts [6]. The impact locations are the bonnet top and windscreen frame (see Figure 1). The HIC and force-deformation characteristics of these cars are compared with those of the 1990 Corolla.

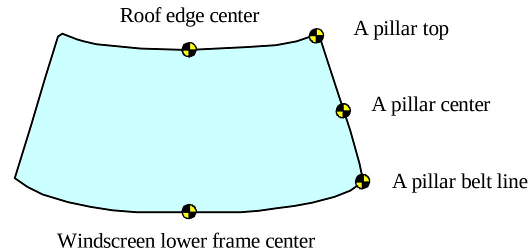


Figure 1. Headform impact locations on the windscreen frame.

Child Headform Impact Test

Test on bonnet top To examine the head injury risk for children, impact tests using a child headform were performed with the Corolla, Life, Sunny and Mitsubishi Pajero. The child headform (2.5 kg) employed is the one proposed by the EEVC [3]. The hood and hood/fender boundary were impacted at WAD of 1200 mm. For all tested cars, this WAD corresponds to the hood. Figure 2 shows the conditions for the adult and child headform impact tests. In some tests, the adult and child headform were impacted on the same car locations. The HIC and force-displacement characteristics are compared.

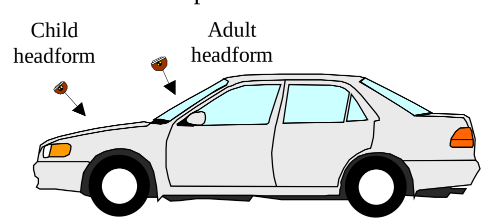


Figure 2. Headform impact tests.

Bull bar test Child headform impact tests were performed for SUV (Vehicle A) with and without a steel bull bar (Figure 3). For this SUV, the bull bar strut is mounted low on both the steel bumper and longitudinal member. Table 1 shows the test matrix. The WAD of impact locations was about 1000 mm, which is almost the head center height of a child aged 5 or 6 years. In the SUV without the bull bar, the bonnet leading edge (WAD 1000 mm) was impacted at 40 km/h, and the results were compared with cars. An impact velocity of 30 km/h was selected for the steel bull bar since even at this low velocity the HIC is predicted to be high level. For comparison, the 30 km/h impact tests were also performed for the SUV without a bull bar.

The impact angle of 50 degrees which is the same as used in the EEVC test procedures, was selected for the SUV without the bull bar because the upper body of child rotates after the pelvis or femur make contact with the bumper. When the child is impacted by the SUV with bull bar, the rotation angle of the upper body is small, so an impact angle of zero was selected.

The plastic bull bar was attached on the SUV (Vehicle B). To examine the energy absorption of the plastic bull bar, the child headform impact test was also performed at an impact velocity of 40 km/h with an angle of zero.

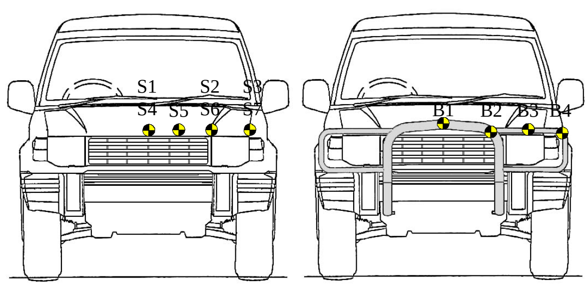


Figure 3. Impact locations of SUV with and without steel bull bar.

Table 1. Child headform impact test on SUV

Test No.	Vehicle	Impact location	Velocity (km/h)	Angle (deg)	WAD (mm)
S1	SUV	Hood leading edge (center)	40	50	1010
S2	SUV	Hood leading edge (right)	40	50	1000
S3	SUV	Hood/fender boundary	40	50	1000
S4	SUV	Hood leading edge (latch)	30	50	1010
S5	SUV	Hood leading edge	30	50	1000
S6	SUV	Hood leading edge	30	50	1000
S7	SUV	Hood/Fender boundary	30	50	1000
B1	SUV	Steel bull bar (center top)	30	0	1010
B2	SUV	Steel bull bar (strut)	30	0	980
B3	SUV	Steel bull bar (top, around light)	30	0	960
B4	SUV	Steel bull bar (corner)	30	0	940
GP	SUV	Plastic bull bar	40	0	930

RESULTS

Headform Impact Test with and around Windscreen

The impact locations and calculated HICs are shown in Figure 4. A total of 40 impact tests were carried out on the hood, fender, cowl, windscreen, and windscreen frame including A pillar. In the hood, cowl and fender areas prescribed in the EU test procedures, the HICs for only two locations are less than the injury threshold (HIC 1000). The rear hood and hood/fender areas produce high HICs. The HICs are extremely high (over 5000) for the hood hinge, hood stopper, corner of the windscreen frame, and bottom of the A pillar.

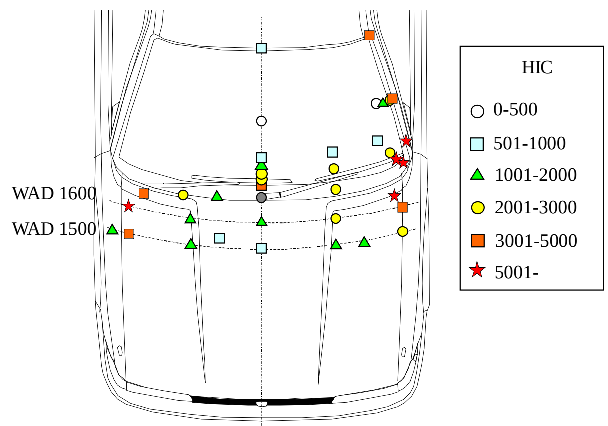


Figure 4 HIC distributions and impact location by impact position for the tested car (40 km/h).

The car body shows various force-deformation characteristics when hit by the headform. Figure 5 shows the force-deformation characteristics of the main locations of the car. In the hood region, the force reaches a peak deformation of 25 mm, and the force decreases in accordance with the rotation of the impactor. The hood at the hinge and the hood stopper produce high force levels of 20 kN. In the cowl area, the force increases consistently, whereas at the wiper pivot, the force is high due to the deformation of the wiper pivot axis. The A pillar has a constant force level due to the collapse of its box shape, yet its force level is high enough to cause serious injuries to the head.

In addition to the baseline force-deformation characteristics of each car body part, the local high stiffness of the hood hinge, hood stopper and wiper pivot were found to have a major effect on both the force-deformation characteristics and the HIC.

The force-deformation characteristics were compared among the lower edge of the windscreen frame, 50, 150 mm above it, respectively, as well as at the windscreen center (Figure 6). In the windscreen area 50 mm above the lower windscreen frame, the force shows an inertial spike of about 7.5 kN in the initial phase when the glass breaks. After that, the force increases, and the force-deformation curve is similar to that of the windscreen frame. For the impact on the center of the windscreen, the initial spike of the glass breaking is followed by a low plateau force of about 3 kN, which is due to stretching of the PVB film of the HPR glass. In this area, the effect of the stiffness of the windscreen frame on the force-characteristics is small. These results show that the force-deformation characteristics of the windscreen are mainly affected by those of the windscreen frame.

The relation between the HIC and the distance from the windscreen frame is examined along the three paths shown in Figure 7. The HIC value is a maximum at the windscreen frame for all paths, and it decreases with the distance from the frame.

The tendency to a lower HIC varies with each windscreen frame. The HIC of path A decreases gradually with the distance from the lower windscreen frame because the headform impactor contacts the top of the instrument panel. However, for the A pillar, the HIC decreases abruptly (path B). At path B, the impactor does not contact the A pillar when the distance from the A pillar is greater than 100 mm. The corner of the windscreen frame is so stiff that the HIC in the windscreen around this corner reaches a high value (path C). The HIC of path C shows a similar tendency to that of path A when the distance from the lower windscreen frame is over 100 mm, which means that the influence of the A pillar is small in this region.

The HIC distributions in the upper region of the windscreen were examined by Matsui et al [7]. A contour map of the whole windscreen is drawn, including these results as shown in Figure 8. The region where the HIC value is below the injury threshold covers much of the windscreen.

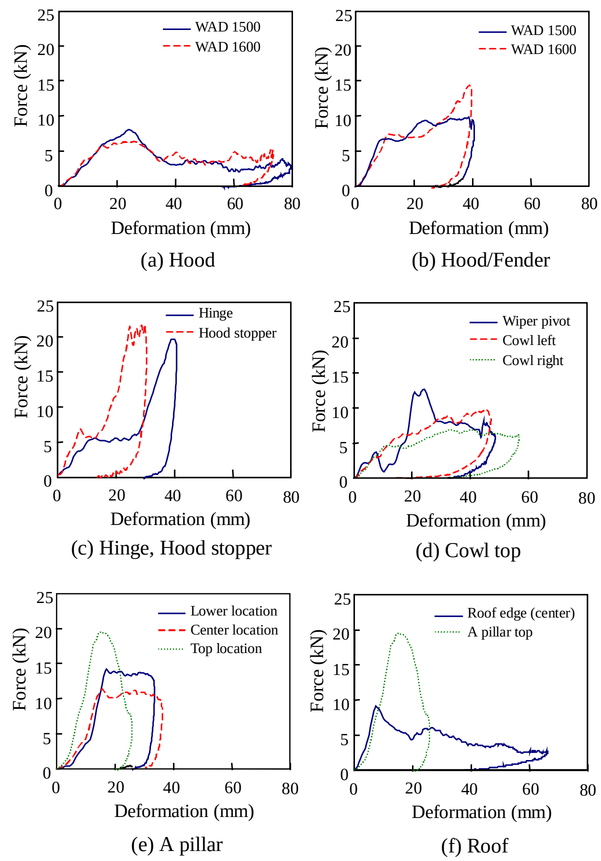


Figure 5. Force-deformation characteristics of the car from headform impact tests (40 km/h).

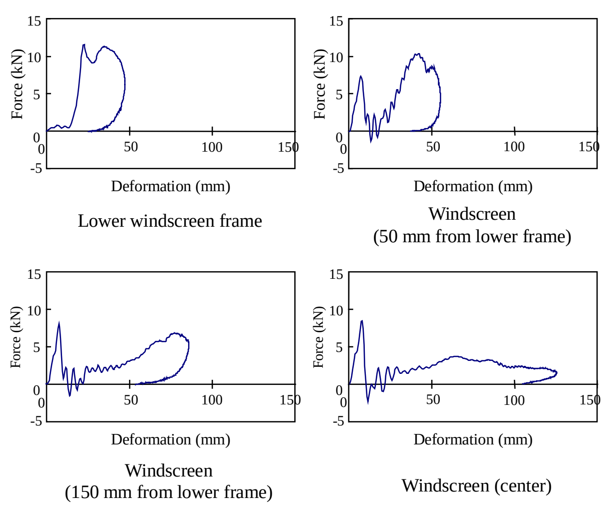


Figure 6. Force-deformation characteristics of the windscreen from headform impact tests (40 km/h).

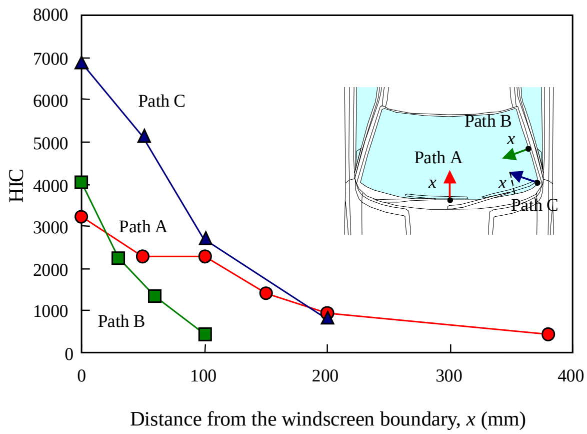


Figure 7. Relation between HIC and distance from windscreen frame of the tested car (40 km/h). Path A is from the lower windscreen frame, path B from the A pillar, and path C from the corner of the windscreen. For path C, the lateral axis indicates the distance from the lower windscreen frame.

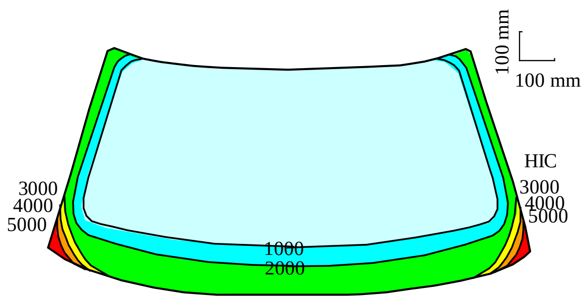


Figure 8. HIC in the windscreen region in the headform impact tests for the tested car (40 km/h). Upper part of the contour map is from Matsui et al [7].

Impact velocity and injury risk

In order to clarify the effects of impact velocity, its relation to the HICs was examined for the hood (WAD 1500 mm on the centerline of the car) and the center of the windscreen. The results are shown in Figure 9. The hood produces a linear increase in the HIC with increasing impact velocity, and the HIC value exceeds 1000 at 50 km/h. When the impact velocity is 50 km/h on the windscreen, the PVB film was torn (there was no penetration of the headform), which results in a HIC value below the injury threshold. Since the HIC for impact with the windscreen is still less than the injury threshold even at the impact velocity of 50 km/h, it is considered the injury risk to the head is low in the center of the windscreen.

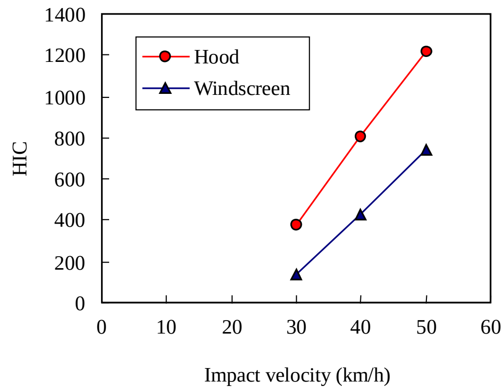


Figure 9. Effect of the impact velocity on the HIC for the tested car.

HIC and dynamic deformation

The deformation necessary to keep the HIC below 1000 is important in order that a car may be designed to reduce the likelihood of pedestrian head injuries. MacLaughlin et al. [8] showed in headform impact tests onto the hood top (37 km/h) that the HIC is related to the dynamic deformation. Since their study experimentally investigated only the hood top, we examined this relation based on theoretical analysis as well as on impact tests for the windscreen and the bonnet top.

The HIC results obtained from the headform impact test on the car body (excluding the windscreen) and the windscreen itself are shown as a function of dynamic deformation in Figure 10. The HIC correlates well with the dynamic deformation of the car body and windscreen.

The approximation curves were calculated for the windscreen and the car body. Based on these approximation curves, a HIC value of 1000 is associated with a dynamic deformation value of 76 mm for the car body for the windscreen. In order to reduce the HIC below 1000, dynamic deformations greater than those values are necessary.

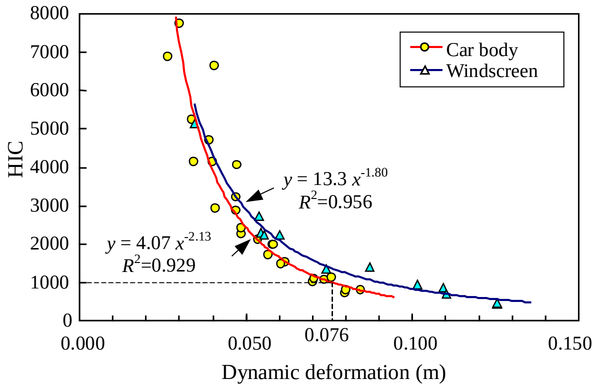


Figure 10. HIC versus dynamic deformation in headform impact tests for the tested car (40 km/h).

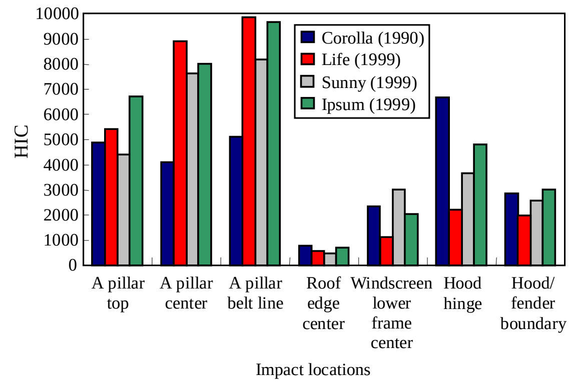


Figure 11. HICs for various locations in four vehicle models (40 km/h).

HICs compared with current and old car models

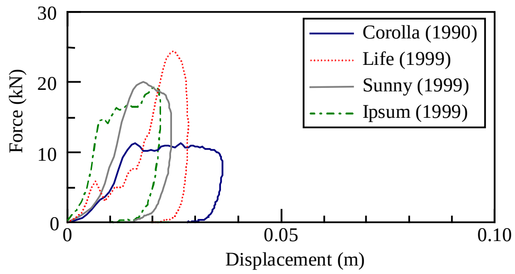
The HICs at various impact locations in four cars are compared in Figure 11. The A pillar produces high HIC for all cars, which indicates that the injury risk to the head is particularly high in impact against this location. For the 1990 Corolla, the HICs at the A pillar are less than 5000, whereas for other current cars the HICs at the center and belt line of the A pillar are more than 7000. Those values are far higher than the injury threshold, and the probability of death is very high. At the center of the roof edge, the HICs are less than 1000 for all cars.

In the hood top area, the HICs of the Corolla are almost the same as those of current car models except Life. For the Life in which the countermeasure are conducted for the head impact, the HIC is almost 1000 at the center of the lower windscreen frame, and less than 2000 at the hood edge and the hood/fender boundary. Therefore, at these locations, the countermeasure can be applied, however, it may be difficult to reduce the HIC less than 1000 for all regions on the bonnet top at an impact velocity of 40 km/h.

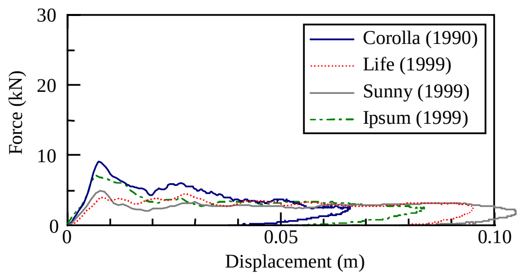
The force-displacement characteristics for the A pillar, roof edge, lower windscreen frame, hood hinge and hood/fender boundary are compared with four cars as shown in Figure 12. The A pillar of the Corolla collapsed at the force level of 10 kN, whereas for other cars the A pillars did not collapse and produced high force levels. In an impact against a roof edge, as the roof bent from its center, the force level is less than 5 kN and the force-displacement curves are similar among the four cars.

Generally the force curves of the current cars are similar to those of Corolla. However, the Life force levels are low as 5 kN at the lower windscreen frame, and 10 kN at the stiff parts like the hood hinge and hood/fender boundaries. Thus, from the countermeasure for pedestrian, cars have the bonnet with low force level, and decreases the injury risk to the pedestrian head.

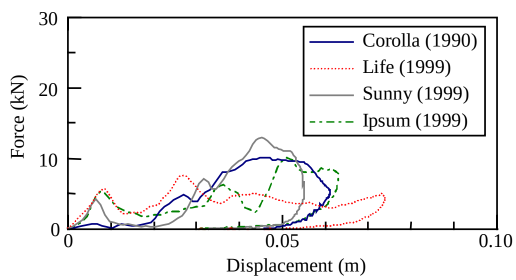
The sections of the A pillar for the 1990 Corolla and 1999 Sunny after impact tests are presented in Figure 13. The A pillar of the Corolla consists of one layer of thin steel, and the A pillar deformed upon impact. On the other hand, the A pillar of Sunny in the impact location consists of two or three layers. The A pillar of the Sunny is so stiff that the deformation was very small and produced extremely high HIC values. One reason for this deformed structure may be the countermeasure for the frontal impact tests, where the A pillar structure is an important structure for the integrity of the passenger compartment.



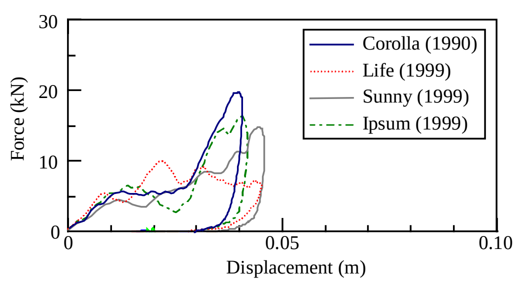
(a) A pillar (center)



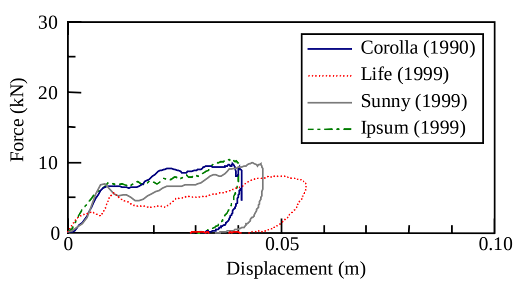
(b) Roof edge (center)



(c) Lower windscreen frame (center)

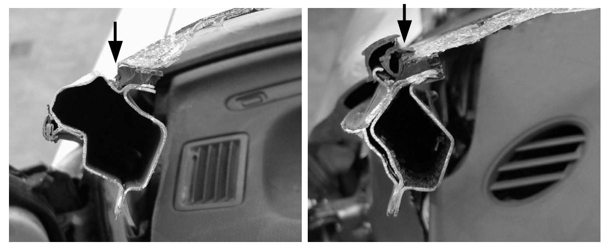


(d) Hood hinge



(e) Hood/fender boundary

Figure 12. Force-displacement characteristics for various locations in adult headform impact tests (40 km/h).



Corolla (MY 1990) Sunny (MY 1999)

Figure 13. Setions of A pillar after headform impact (40 km/h). Arrow shows impact point.

Child headform impact tests

Impact tests on hood top The HIC of child headform impact tests on the hood and hood/fender boundary for four vehicles are shown in Figure 14. The HICs in hood are almost same level in tested cars. The HIC at the hood of the SUV is higher than other cars due to its stiff hood. In the hood/fender area, the HIC of Corolla is above 3000 but that of other cars is ranging from 2000 to 3000. Figure 15 shows the force-displacement characteristics for hood and hood/fender boundary. The curve shapes are similar in tested cars, and the force level of the Life is smaller than other cars.

Adult and child headform tests at 40 km/h were performed on the same car location (Figure 16). The initial stiffness is similar between adult and child headform, but the final force level is higher for adult headform. The HIC of the child headform is higher than that of the adult headform. The difference between them is not so very large, although the ratio of the impactors is 1.92 (=4.8/2.5).

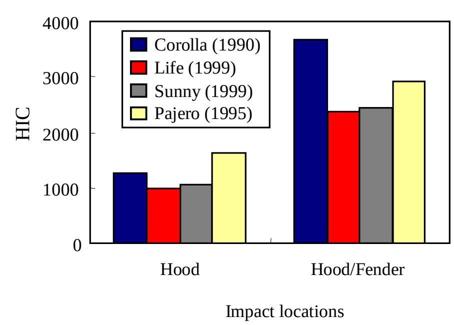
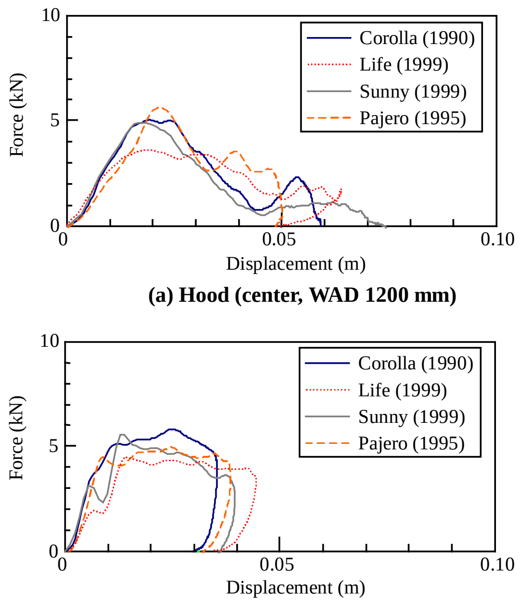


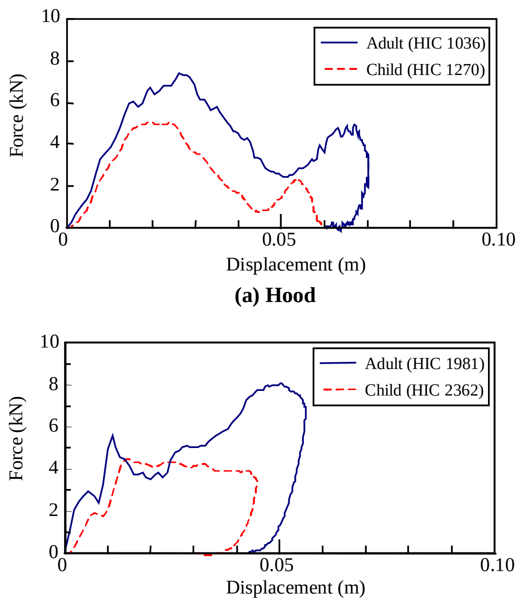
Figure 14. HICs in child headform impact tests (40 km/h).



(a) Hood (center, WAD 1200 mm)

(b) Hood/fender boundary (WAD 1200 mm)

Figure 15. Force-displacement characteristic in child headform impact tests.



(a) Hood

(b) Hood/Fender boundary

Figure 16. Force-displacement characteristics in an impact at the same location by adult and child headform (40 km/h).

Bull bar tests The HICs of the SUV are high even without the bull bar. Since the WAD 1000 mm corresponds to the hood leading edge of the SUV, the HIC is above 2000. Especially at the center of the hood leading edge where there is a hood latch, the HIC is 3415. The WAD 1000 mm is for the hood of the car, whereas it is the hood leading edge for the SUV. Therefore, the injury risk to the head of child is higher for SUV than that of cars, since the head is likely to contact an area of high stiffness. This may be one reason for the high injury risk to children aged 5 or 6 years old in an impact against the SUV compared with cars.

Figure 17 shows the acceleration-time histories of the steel bull bar at 30 km/h. The acceleration became high when the bull bar rotates from its mount at the bumper. The pulse deviation after 5 ms is due to the vibration of the headform impactor itself. No residual local deformation of the steel bull bar was observed.

The results of SUV with and without the bull bar are compared for the impact velocity of 30 km/h. At the center tube top (B1) or strut of the bull bar (B2), higher HIC are produced than at the hood leading edge of the SUV (S4, S5, S6). On the other hand, the bull bar around lamp (B3) or corner (B4), the HICs are less than those without the bull bar (S6, S7). However, a small-diameter of the bull bar in these locations may cause focal injury to the head because of force concentration from the bull bar [9]. Generally, the injury risks from the steel bull bar are higher than those of the SUV without the bull bar.

Table 2. Child headform impact test results on SUV with and without bull bar

Test No.	Impact location	Velocity (km/h)	Angle (deg)	HIC
S1	Hood leading edge (center)	40	50	3415
S2	Hood leading edge (right)	40	50	2189
S3	Hood/fender boundary	40	50	3763
S4	Hood leading edge (hood	30	50	1459
S5	Hood leading edge	30	50	1169
S6	Hood leading edge	30	50	1194
S7	Hood/fender boundary	30	50	1724
B1	Steel bull bar (center top)	30	0	3272
B2	Steel bull bar (strut)	30	0	3793
B3	Steel bull bar (top, around	30	0	994
B4	Steel bull bar (corner)	30	0	446
GP	Plastic bull bar	40	0	1106

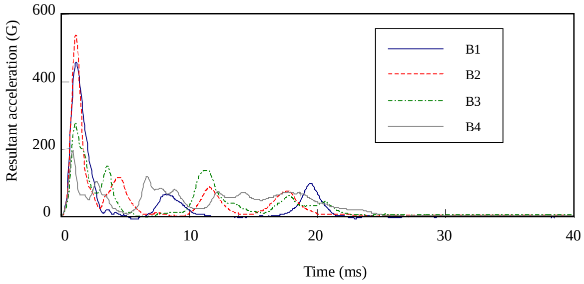


Figure 17. Acceleration-time histories for steel bull bar (30 km/h).

The plastic bull bar in a child headform impact is presented in Figure 18. The bull bar was cracked and absorbed impact energy. Figure 19 shows the acceleration-time history. The acceleration is low and the duration time is long. The HIC is slightly more than 1000 at 40 km/h, far lower than that of SUV with or without the steel bull bar.

Figure 18. Plastic bull bar impact tests using child headform (40 km/h, time=10 ms).

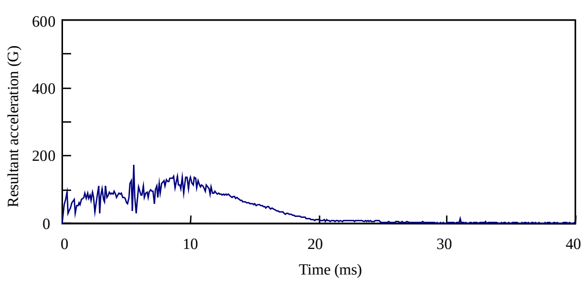


Figure 19. Acceleration-time history in impact against plastic bull bar (40 km/h).

CONCLUSIONS

Head injury risk in pedestrian impact with vehicles was examined based on headform impact tests. The results are as follows:

1. From the adult headform impact tests, the distributions of the HIC in the windscreen were obtained and the HIC was maximal at the windscreen frame.
2. The A pillar produces high HIC, and this tendency is more remarkable for current cars due to the high stiffness of the A pillar.
3. A car with built-in the countermeasures to protect the pedestrian head produces low HIC and force levels.
4. A steel bull bar produces higher injury risk to the child head than the SUV without SUV, whereas a plastic bull bar can absorb the impact energy and reduce the injury risk.

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